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RHIC forward experiment to study $\sqrt{s}$ dependence of forward particle production

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Abstract. The Relativistic Heavy Ion Collider forward experiment is ready to take data in the RHIC Run2017 $\sqrt{s} = 510$ GeV p-p collisions using the LHCf Arm1 detector. New accelerator data are valuable to verify the Feynman scaling of π^0 production and to study the evolution of the break of scaling in neutron production. Using the transversely polarized proton beam, asymmetric production of forward neutrons is precisely measured. That is useful to understand the fundamental meson exchange in the proton-proton collisions.

1. Introduction

Hadronic interaction models used in the analyses of air shower observations are extensively tested using the forward and minimum bias events at the Large Hadron Collider (LHC) [1].The LHC provides the highest collision energy corresponding to the cosmic-ray interaction energy of 10^{17} eV. However, measurements at lower energies using the pre-LHC colliders are not available such as the LHC case. Even though the interaction is better understood at the LHC energy range, experimental data are not enough to extend the knowledge beyond the LHC energy, or even below.

To extrapolate the accelerator results to the arbitrary collision energy, which is required for cosmic-ray analysis, verification of scaling or $\sqrt{s}$ dependence is important. The LHCf experiment [2] reported that the differential cross sections of forward π^0 production in x_F-p_T phase space hold the Feynman scaling [3] between $\sqrt{s} = 2.76$ TeV and 7 TeV p-p collisions [4]. A similar scaling was also reported [5] for forward neutron production between the ISR [6] and PHENIX [5] experiments at $\sqrt{s} = 30$–60 GeV and 200 GeV, respectively. On the other hand, the LHCf result at $\sqrt{s} = 7$ TeV indicates a break of the scaling [7,8]. To extend the verification of the scaling in π^0 production or to study the evolution of the break of scaling in neutron production, 510 GeV p-p collisions at the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory is a unique opportunity.

In this paper, a new experiment *RHIC forward* [9] ready to take data in 2017 is reviewed. The overview, operation plan and expected results of the experiment are introduced in Sect. 2.1, Sect. 2.2 and Sect. 2.3, respectively. Another scientific target, the measurement of the single-spin asymmetry of the forward particles, is also introduced in Sect. 2.4.

2. The RHIC forward experiment

2.1. Experimental overview

The RHICf experiment uses one of the LHCf detectors, LHCf Arm1 [2]. The RHICf detector is installed in the West side of the STAR experiment, 18 m away from the interaction point. The detector is located between two beam pipes connected to the arc of the storage ring as shown in Fig. 1 (left) and the Zero Degree Calorimeter [10] is located behind the detector. Because there is a dipole magnet between the interaction point and the detector, only neutral particles emitted around zero degree arrive at the detector. The detector is composed of two compact sampling calorimeters with position sensitive layers as

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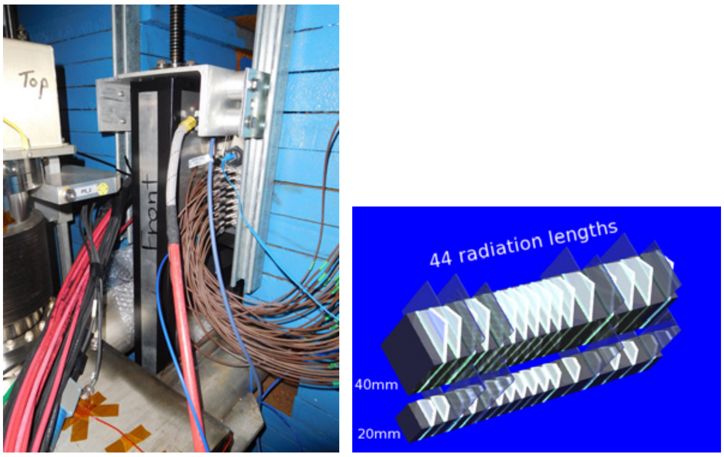

Figure 1. Left: a photo of the RHICf detector installed at 18 m from the STAR interaction point in the RHIC. Right: schematic view of the RHICf calorimeters.

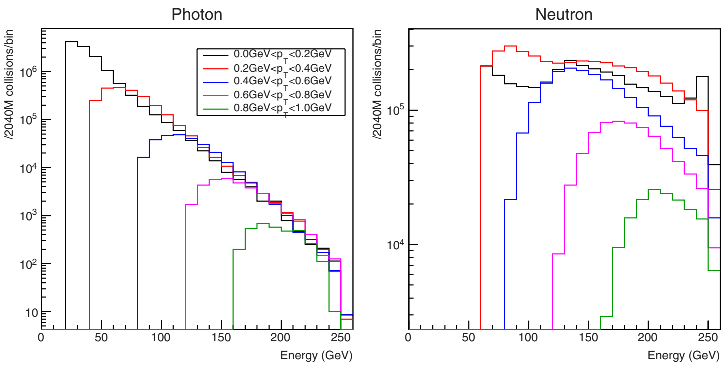

Figure 2. Expected observed spectra of single photon (left) and neutron (right) events after 12 hours of data taking. Data acquisition efficiency is taken into account, but the resolution is not considered.

shown in Fig. 1 (right) and covers pseudorapidity $\eta > 6$ by changing the position vertically. The performance of the RHICf detector (the LHCf Arm1 detector) was well studied using the test beams at the CERN SPS North area site [11, 12]. The energy range of the beam test, 100–250 GeV electron beams and 150–350 GeV hadron beams, is perfectly matching with the RHIC energy.

2.2. Operation plan

To measure the production angle of each particle precisely, RHICf requests more parallel beams than the usual RHIC operation, namely $\beta^* = 10$ m. This reduces the luminosity of RHIC down to $2.0 \times 10^{31}\,\text{cm}^{-2}\,\text{s}^{-1}$. This is ideal when considering the data acquisition speed of the RHICf and the event statistics. As discussed in Sect. 2.4, the proton beams will be radially polarized.

The RHICf detector will measure photons and neutrons of energy above about 50 GeV. Exact threshold will be determined at the actual operation condition and is different between photons and neutrons. By detecting photon pairs hitting two calorimeters simultaneously, π^0's are identified. Because the data acquisition speed of the RHICf is limited to 1 kHz, only 5% of single particle events are recorded but all π^0 events are recorded at 100 Hz.

A week of special physics operation time is approved for the RHICf in early June 2017, at the end of the 510 GeV p-p run. Two days for the special beam setup and two days for physics data taking are scheduled. During the RHICf operation period, STAR will record the collision data according to the trigger of the RHICf. Test of common data record and its offline confirmation is ongoing between the RHICf and STAR collaborations.

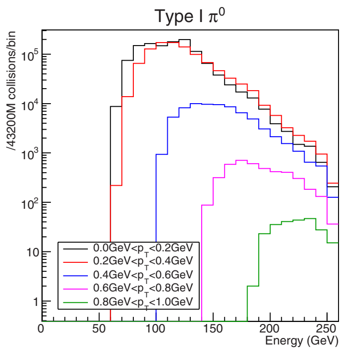

Figure 3. Expected observed spectra of π^0 events after 12 hours of data taking. All photon pair events are assumed to be recorded.

2.3. Expected results

Figure 2 shows the expected spectra of photons and neutrons in 12 hours of operation calculated using the EPOS-LHC model. The limit of the data acquisition speed is taken into account while the energy resolution is not considered. Operation at three vertical positions of the detector are assumed. Peculiar structure in the neutron spectra is due to the geometrical effect of the calorimeter

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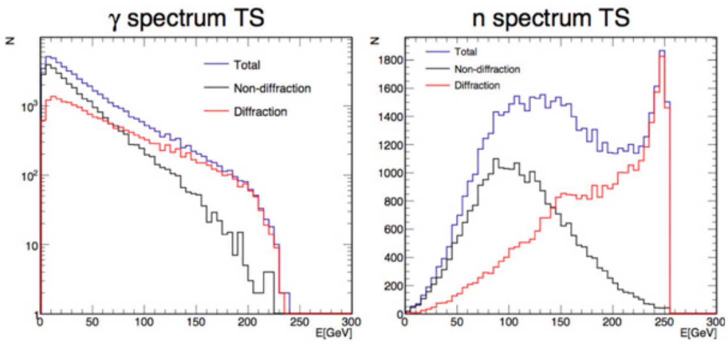

Figure 4. Expected spectra of photons (left) and neutrons (right) around 0° using PYTHIA 8212. Red and black histograms show the spectra originated from the diffractive and non-diffractive processes while purple show the total inclusive spectra.

shape and the positional scan. It is found, except for high-energy and high-p_T photons, <1% statistical accuracy is obtained with a 10 GeV binning in a wide energy and p_T region. A special trigger is in preparation to enhance the statistics of the high-energy photons.

Spectra of π^0s expected in the same operation time are shown in Fig. 3. Another special trigger allows all events with photons in two calorimeters to be recorded. It is found that in most of the region 1 - few % statistical accuracy is achieved. This will be slightly smaller than the expected uncertainty in the luminosity determination.

Because RHICf will take data with STAR, joint analyses will make new possibilities in the physics analyses. A joint analysis with the ZDC will improve the energy resolution of the neutron measurement. The advantages of the RHICf detector and the ZDC, high position resolution and high energy resolution, respectively, complement each other. Correlation between the forward and the central regions is useful to separate diffractive and non-diffractive interactions. Fig. 4 shows spectra of very forward photons and neutrons to be measured by RHIC calculated by PYTHIA 8212. The purple histograms indicate the inclusive spectra measured by the RHICf alone while the red and black histograms show the contributions from diffractive and non-diffractive interactions, respectively. It is interesting that the contributions from the two processes are similar but the shape is very different. It is shown that the information in the central tracker is powerful to distinguish two processes in the case of the ATLAS-LHCf common analysis [13], and the same method is applicable to the STAR-RHICf case.

2.4. Single-spin asymmetry measurement

Experiments at RHIC discovered an unexpectedly high azimuthal asymmetry of forward neutron production when transversely polarized proton beams collide [5,14]. Combining the data taken from three different $\sqrt{s}$, it is suggested that the amplitude of the asymmetry is proportional to p_T [15]. This p_T scaling of the forward neutron asymmetry is theoretically explained considering the interference in the scattering amplitudes of pion and a_1 mesons [16]. However, because of the limited position resolution in the measurement, p_T coverage was limited to <0.4 GeV and the coverages of the different datasets do not overlap each other. This prevents a definitive conclusion on the production mechanism of forward neutrons. To cover a wide p_T in a single $\sqrt{s}$ dataset, excellent position resolution of the RHICf detector is suitable. Thanks to the 1 mm position resolution of the RHICf detector [12] instead of the 10 mm resolution in the former measurement and the vertical position scan, RHICf can cover from 0.05 GeV to 1.2 GeV only in the single $\sqrt{s} = 510$ GeV.

Because the RHICf detector has a wide acceptance in the vertical direction, it is sensitive to the asymmetry in the vertical. To maximize the vertical asymmetry, collisions of radially polarized beam is required. Because this is not a usual setup of the RHIC polarized beams, RHICf requires 1 day for beam setup of radial polarization. As seen in Fig. 2, in parallel to the cross section measurements for cosmic-ray physics, a sufficient number of neutrons are observed. Using the same dataset shown in Fig. 2 and assuming a 50% polarization, the asymmetry amplitude can be determined with the statistical accuracy <0.2% at p_T<0.6 GeV and <1% at p_T<1.2 GeV.

3. Summary

A new experiment, RHICf, is ready to take data in early June 2017 in the RHIC Run2017 $\sqrt{s} = 510$ GeV p-p collisions. Using the former LHCf Arm1 detector, test of the Feynman scaling over a very wide $\sqrt{s}$ will be available. $\sqrt{s}$ dependence of the high-energy hadronic interaction is important to extrapolate the accelerator data to cosmic-ray physics. Using the unique polarized beam at the RHIC, RHICf can also measure the single-spin asymmetry of forward neutron production more precisely than previous measurements. This helps an understanding of the fundamental meson exchange in the p-p collisions.

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